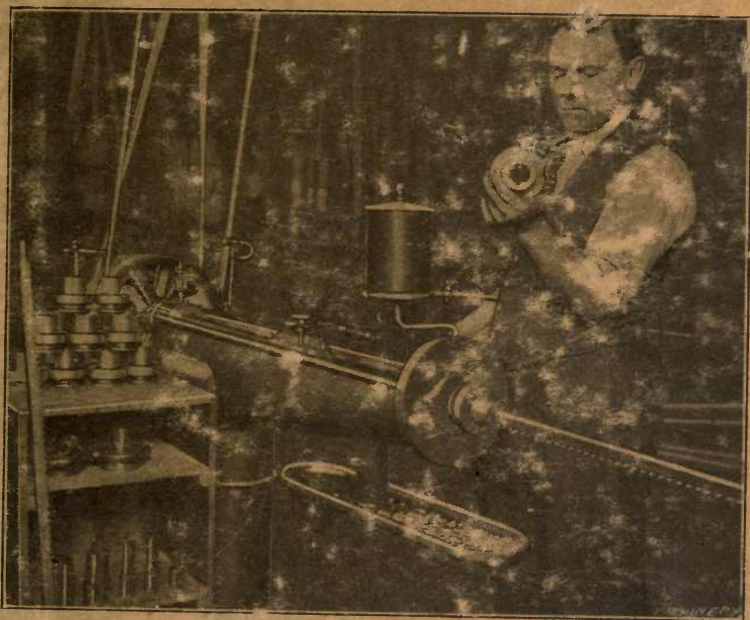
CENTS

BROACHING

BROACHING MACHINES—BROACH MAKING
BROACHING OPERATIONS



MACHINERY'S REFERENCE BOOK NO. 122
PUBLISHED BY MACHINERY, NEW YORK

MACHINERY'S REFERENCE SERIES

EACH NUMBER IS ONE UNIT IN A COMPLETE LIBRARY OF MACHINE DESIGN AND SHOP PRACTICE REVISED AND REPUBLISHED FROM MACHINERY

NUMBER 122

BROACHING

CONTENTS

PREFACE

The cutting of keyways and machining of holes in metal to shapes other than round by broaching is an old practice, but one that has attracted comparatively little attention until within the past ten years. While machines were built and used for broaching they were not in common use until about 1900, when the automobile business developed rapidly. Now the broaching process is used very extensively, not only by automobile manufacturers but by many other concerns. While relatively large work is being broached at the present time, the trend of practice indicates that much larger and heavier parts will be machined in this manner when the quantity of work warrants the necessary investment in machines and tools. The broaching machine is also becoming a recognized means of cutting external shapes that are readily machined with standard tools. The reason for this practice is the high rate of production and low cost.

The advantages of the broaching process are speed, interchangeability of work, adaptability to irregular forms, employment of comparatively unskilled labor, and adaptability to a great variety of work. The chief disadvantage is the high cost of broaches and the uncertainty of their life. One broach may cut 20,000 holes while another made of the same steel and tempered in the same manner may fail before 2000 are cut. While chiefly applied now to interior work, exterior work is also being successfully done, and one of the possibilities is broaching spur gears when the quantity of duplicate gears is large.

In preparing this treatise on broaching, many examples from practice have been included, and we desire to acknowledge our indebtedness especially to the J. N. Lapointe Co., and the Lapointe Machine Tool Co. for much practical information relating to modern broaching methods.

CHAPTER I

THE BROACHING PROCESS—BROACHING MACHINES

The broaching process consists in machining holes in castings or forgings by drawing or pushing through the rough cored or drilled hole one or more broaches having a series of teeth which increase slightly in size from one end of the tool to the other, and successively cut the hole to the required form. Broaching is especially adapted to the finishing of square, rectangular or irregular-shaped holes. It is also applicable to a wide variety of miscellaneous work, such as the

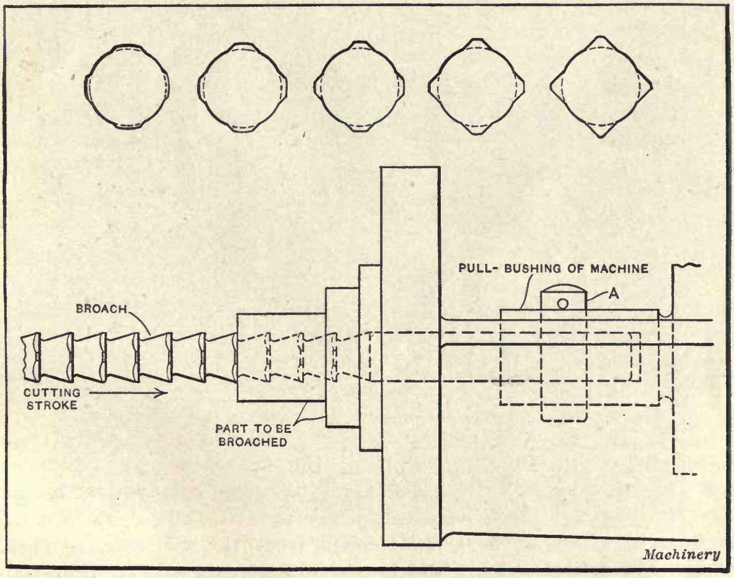


Fig. 1. Diagram Illustrating Method of Broaching a Square Hole

cutting of single or multiple keyways in hubs, forming splines, cutting teeth in small internal gears and ratchets, etc.

There are two general methods of broaching: One is by pushing comparatively short broaches through the work, usually by means of a hand press, a hydraulically operated press, or an ordinary punch press. With the other method, a special broaching machine is used, and the broach, which is usually much longer than a "push broach", is pulled through the work by means of a screw forming part of the machine. Push broaches must necessarily be quite short to prevent excessive deflection; consequently it is often necessary to force several broaches through the work. The longer broaches which are

pulled through in regular broaching machines commonly finish parts in one passage, although a series of two or more broaches are often used for long holes, or when considerable stock must be removed. The number of broaches ordinarily used varies from one to four. Comparatively short broaches are sometimes used, because they are easier to make, are not warped excessively in hardening and are easier to handle. Two or more parts can frequently be finished simultaneously on a regular broaching machine, the pieces being placed one against the other, in tandem.

A simple example of broaching by drawing the broach through the work is illustrated by the diagrams, Fig. 1. A square hole is to be broached in the hub of a gear blank, this being a sliding gear (such as

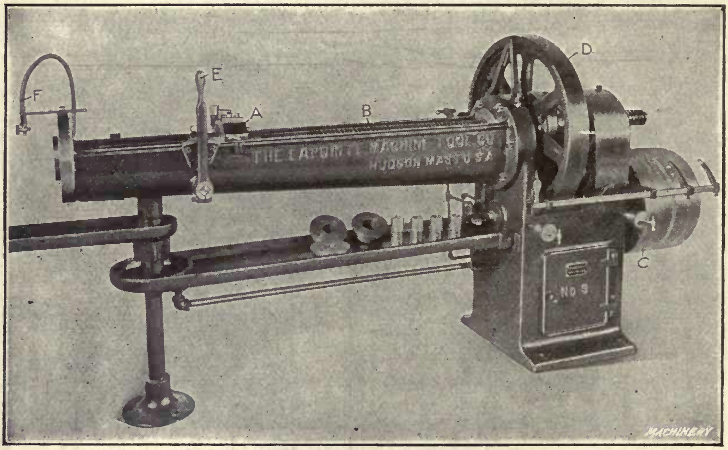


Fig. 2. Broaching Machine made by the Lapointe Machine Tool Co.

is used in automobile transmissions) that is to be mounted upon a square driving shaft. Prior to broaching, a hole is drilled slightly larger in diameter than the width of the square. The starting end of the broach, which at first is detached from the machine, is passed through the drilled hole in the blank, which rests against the end of the broaching machine. The end of the broach is then fastened to the "pull bushing" by a key *A* (which fits loosely to facilitate its removal), and the machine is started. By means of a powerful screw the broach is drawn through the hole in the gear blank and this hole is gradually cut to a square form by the successive action of the teeth which increases in size 0.002 or 0.003 inch per tooth. The process is illustrated by the enlarged diagrams at the top of the illustration.

The first few teeth take broad circular cuts which diminish in width so as to form a square-shaped hole. Of course, it will be understood that for cutting a hexagonal, round, or other form of hole, a broach of corresponding shape must be used. The blank to be broached does not need to be fastened to the machine, but is simply slipped

onto the broach or a work bushing, in some cases, in a loose manner. As soon as the broaching operation begins, the work is held rigidly against the end of the machine or fixture when the latter is used.

From the preceding description of the broaching process, it will be seen that the function of the broaching machine is to draw the broach through the work at the proper speed.

General Description of a Broaching Machine

A typical broaching machine is illustrated in Fig. 2. The broach is secured to a draw-head *A* which in turn is attached to the end of

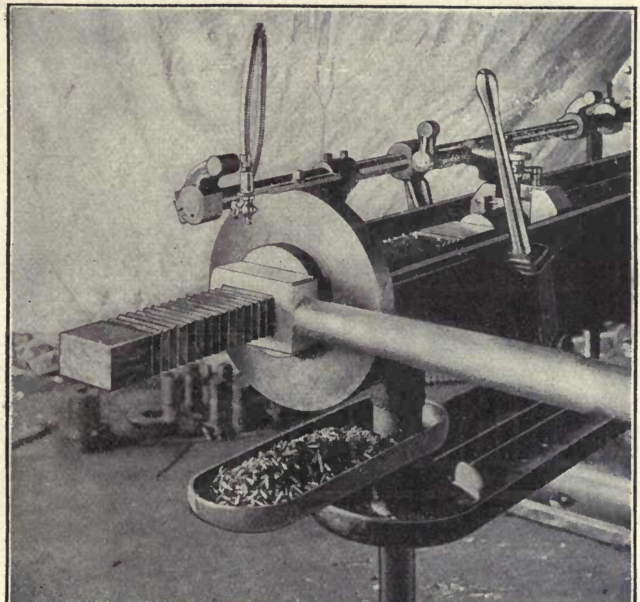


Fig. 3. Broaching Engine Connecting-rod End

a large screw *B*. This screw passes through a phosphor-bronze nut which is held against endwise movement and is rotated through gearing connected with the belt driving pulley *C*. As the nut rotates, screw *B* is moved one way or the other, depending upon the direction of rotation. On the broaching or cutting stroke, the drive is from a pinion on the belt pulley shaft, to a large gear (enclosed by guard *D*), which is connected to the screw operating nut by a clutch. On the return stroke, the clutch is shifted out of mesh with the large gear and is engaged with a smaller and more rapidly moving gear which rotates in the opposite direction.

The stroke of the machine is automatically controlled by two adjustable tappets mounted on a rod extending along the rear side. When either of these tappets is engaged by an arm which extends

backward from the draw-head *A*, the rod upon which they are mounted is shifted. This movement of the rod operates the clutch, previously referred to, which reverses the motion of the nut on the screw. The stroke of the machine is regulated by simply changing the position of the tappets. The vertical lever *E* operates this same tappet rod and is used to start, stop or reverse the movement of the machine by hand. Cutting lubricant for the broach is supplied through the flexible tube *F*. These are the principal features of a broaching machine of the type illustrated.

Broaching a Connecting-rod End

A simple example of broaching is illustrated in Fig. 3 which shows how the rectangular opening in the end of an engine connecting-rod is finished. The hole is 2¼ inches wide by 4½ inches long, and the

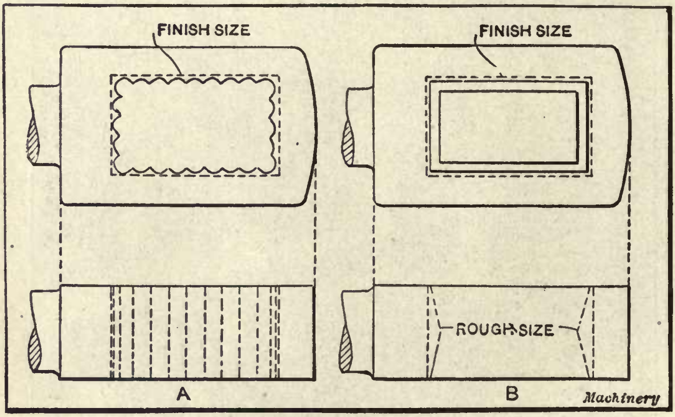


Fig. 4. (A) Rod End Blocked Out by Drilling. (B) Rod with Forged Hole

end of the rod is 1⅞ inch thick. This rectangular opening is finished by broaching in from four to five minutes, the time depending somewhat upon the facilities for handling the work. The end of the rod, prior to the broaching operation, is either blocked out by jig drilling as indicated at *A*, Fig. 4, or a rough hole is formed by forging as indicated at *B*. The full lines in these sketches show the rough surfaces in each case, and the dotted lines, the finished hole.

For broaching an opening of this size, two operations are required; one for roughing and one for finishing. The roughing broach removes the greater part of the metal and enlarges the hole to within 1/16 inch of the required size, there being 1/32 inch left on each of the four faces for finishing. The starting end of the finishing broach fits into the hole made by the roughing broach. These broaches are made of a solid piece of steel and are approximately 48 inches long.

As each of these rods weighs from three hundred to four hundred pounds, they are usually handled by means of a hoist. The end of

the rod to be broached is supported by the broach itself, and the opposite end rests on a suitable stand. In this way, the work is held parallel or in position to bring the finished hole in alignment with the rod. The broach operates in a fixed position and finishes the hole according to the way the rod is set. After the support is properly located, any number of pieces can be broached without further adjustment, the holes produced being uniform in size and in alignment with the rod.

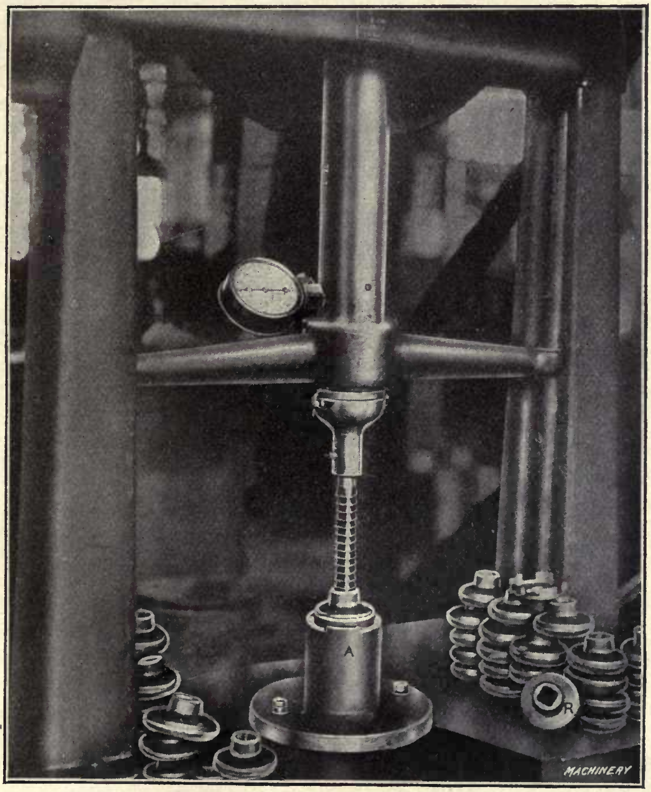


Fig. 5. Broaching Square Holes in a Vertical Hydraulic Press

Broaching in a Vertical Press

Fig. 5 shows an example of "push broaching," comparatively short broaches being forced down through the work by means of a hydraulic press. The operation is that of broaching the holes for the squared ends of the live spindles of the rear axle in the axle dogs in an automobile plant. The dogs are held in position by the hollow jig *A*, which is bolted to the base of the press, the jig being slotted to conform to the teeth of the dog, as shown at *D*. As the ram of the press forces the broach through the hole, the dial shown registers

the pressure in tons; the maximum allowable pressure is 30 tons. At *R* is shown one of the dogs after it has been broached.

Duplex Broaching Machine

A duplex or double type of broaching machine is illustrated in Fig. 6. The distinctive feature of this machine is that there are two operating screws so that two broaches can be used at the same time. The design of the machine is such that one head is being returned while the other is on the cutting stroke. As it is possible to disengage one of the operating screws, the machine can be changed into the equivalent of a single broaching machine if desired. Both operating screws are provided with individual trips for regulating

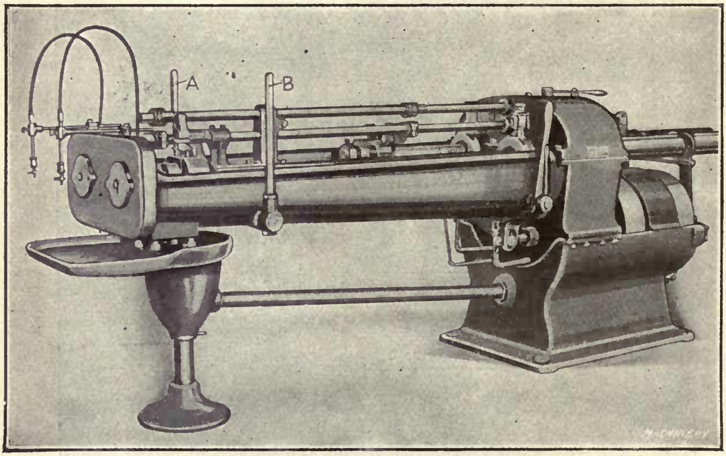


Fig. 6. Duplex Broaching Machine made by the J. N. Lapointe Co.

the length of the stroke. These trips are mounted upon rods which are located above the operating screws. Two broaching speeds are available, and two operating levers *A* and *B* are used to control the machine from either side. There is a pump and oil reservoir in the base of the machine to supply lubricant to the broaching tools. Two flexible tubes at the front end of the machine direct the cutting compound upon the broaches at the point where the cutting action takes place.

Means are provided for adjusting the stroke of the machine so that each screw operates on the same length of stroke. When making the adjustment, one of the sliding heads is brought into position ready for the cutting operation. The lever seen at the top of the gear-case is then moved sideways to disconnect this head. The operating lever on the machine is next shifted to the working position, and the other sliding head is moved to a position corresponding with the extreme length of stroke required. The stops are then set in this position and the stops for the other head are set in alignment with them. The lever on top of the gear-case is then shifted to

bring the first head into operation. The travel of the sliding head on the low speed is 3 feet per minute, and on the high speed, 6 feet per minute. The maximum stroke of the machine is 54 inches, and it has a capacity for broaching holes up to 3 inches square.

CHAPTER II

BROACHES AND BROACH MAKING

A number of typical broaches and the operations for which they are intended are shown by the diagrams, Fig. 7. Broach *A* produces a round-cornered, square hole. Prior to broaching square holes, it is usually the practice to drill a round hole having a diameter *d* somewhat larger than the width of the square. Hence, the sides are not completely finished, but this unfinished part is not objectionable in most cases. In fact, this clearance space is an advantage during the broaching operation in that it serves as a channel for the broaching lubricant; moreover, the broach has less metal to remove. Broach *B* is for finishing round holes. Broaching is superior to reaming for some classes of work, because the broach will hold its size for a much longer period, thus insuring greater accuracy, and more economical results are obtained on certain classes of work.

Broaches *C* and *D* are for cutting single and double keyways, respectively. The former is of rectanglar section and, when in use, slides through a guiding bushing which is inserted in the hole. Broach *E* is for forming four integral splines in a hub. The broach at *F* is for producing hexagonal holes. Rectangular holes are finished by broach *G*. The teeth on the sides of this broach are inclined in opposite directions, which has the following advantages: The broach is stronger than it would be if the teeth were opposite and parallel to each other; thin work cannot drop between the inclined teeth, as it tends to do when the teeth are at right angles, because at least two teeth are always cutting; the inclination in opposite directions neutralizes the lateral thrust. The teeth on the edges are staggered, the teeth on one side being midway between the teeth on the other edge, as shown by the dotted line.

A double cut broach is shown at *H*. This type is for finishing, simultaneously, both sides *f* of a slot, and for similar work. Broach *I* is the style used for forming the teeth in internal gears. It is practically a series of gear-shaped cutters, the outside diameters of which gradually increase toward the finishing end of the broach. Broach *J* is for round holes but differs from style *B* in that it has a continuous helical cutting edge. Some prefer this form because it gives a shear-

ing cut. Broach *K* is for cutting a series of helical grooves in a hub or bushing. The work rests against a special rotating support, and revolves to form the helical grooves, as the broach is pulled through.

In addition to the typical broaches shown in Fig. 7, many special designs are now in use for performing more complex operations. (Some of these will be referred to later.) Two surfaces on opposite sides of a casting or forging are sometimes machined simultaneously by twin broaches and, in other cases, three or four broaches are drawn

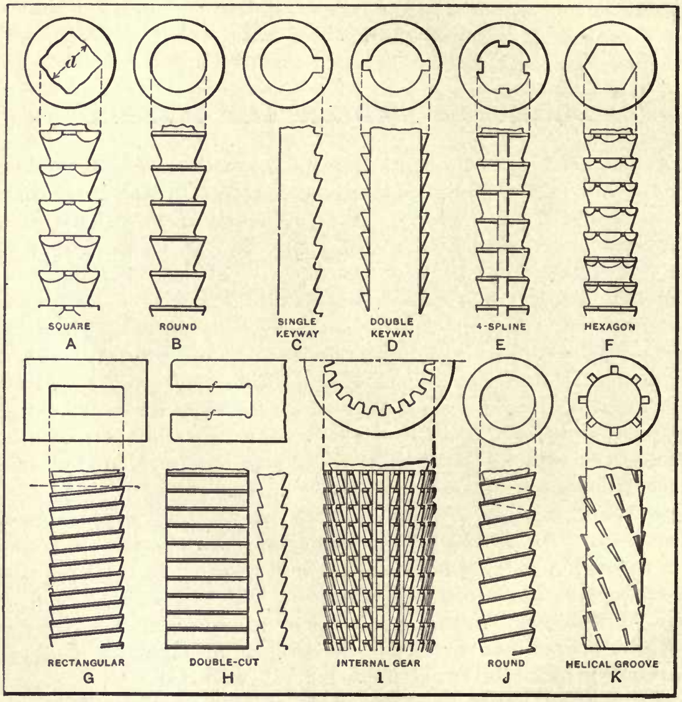


Fig. 7. Types of Broaches and Examples of Broached Work

through a part at the same time, for finishing as many duplicate holes or surfaces. Special work-holding and broach-guiding fixtures are commonly used for multiple broaching. In Chapter III a variety of special broaching operations are described and illustrated and indicate in a general way the possibilities of the broaching process.

As broaches have a series of teeth that successively cut the work to the required form, naturally the proportioning of these teeth is one of the most important features of broach design. While the design of a broach, aside from its general shape or form, depends largely upon its intended use, there are certain features which apply to broach making in general. One of the first things to determine is the pitch of the teeth, or the distance from one tooth to the next.

Pitch of Broach Teeth

As a general rule, the pitch P (see Fig. 8) should increase as the length of the hole increases to provide sufficient space between the teeth for the chips. The pitch of the teeth for broaching under *average* conditions can be determined by the following formula, in which P = pitch of teeth and L = length of hole to be broached:

$$P = \sqrt{L} \times 0.35$$

This formula expressed as a rule would be: *The pitch of the teeth equals the square root of the length of the hole multiplied by the constant 0.35.* For example, if a broach is required for a square hole 3 inches long, the pitch of the teeth would equal $\sqrt{3} \times 0.35 = 0.6$ inch, approximately.

Of course a given pitch will cover quite a range of lengths, the maximum being the length in which the chip space will be completely filled. The constant given in the preceding formula may be as low as 0.3 for some broaches and as high as 0.4 for others, although the

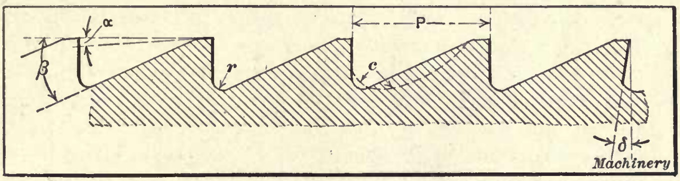


Fig. 8. Diagram illustrating Pitch, Clearance, Rake, and Filleting

pitch obtained with the value 0.35 corresponds to average practice. When a broach is quite large in diameter, thus permitting deep chip spaces in front of the teeth, the pitch might be decreased in order to reduce the total length of the broach. On the other hand, if the work is very hard and tough, a coarser pitch might be advisable in order to reduce the power required to force the broach through the hole.

If the pitch is too fine in proportion to the size of the broach, there may be difficulty in hardening, owing to the fact that the fine teeth will cool much more rapidly than the broach body, thus producing severe strains which tend to crack the teeth, especially at the corners. If the teeth are too closely spaced, so much power may be required for drawing the broach through the work that there is danger of pulling the broach apart. In general, the pitch should be as coarse as possible without weakening the broach too much, but at least *two teeth should be in contact* when broaching work of minimum length.

Depth of Cut per Tooth

The amount of metal that the successive teeth of a broach should remove, or the increase in size per tooth, depends largely upon the hardness or toughness of the material to be broached. The size of the hole in proportion to its length also affects the depth of cut, so that it is impossible to give more than a general idea of the increase

in size per tooth. Medium-sized broaches for round or square holes usually have an increase of from 0.001 to 0.003 inch per tooth for broaching steel, and approximately double these amounts for soft cast iron or brass. Large broaches up to 2 or 3 inches may have an increase of from 0.005 to 0.010 inch per tooth. Obviously, the depth of cut is governed almost entirely by the nature of the work. For example, a small broach for use on brass or other soft material might have a larger increase per tooth than a much larger broach for cutting steel. If the amount of metal to be removed is comparatively small and the broach is used principally for finishing, the increase per tooth may not be over 0.001 inch even for large broaches.

The diagrams *A* and *B*, Fig. 9, show a common method of broaching square holes in the hubs of automobile transmission gears, etc. Prior to broaching, a hole is drilled slightly larger in diameter than the

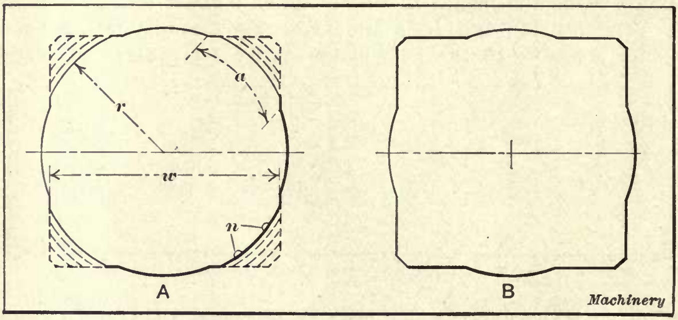


Fig. 9. Diagram illustrating Distribution of Tooth Cuts in broaching a Square Hole

square width. The first tooth on the broach is rounded and cuts a long circular chip, as indicated at *a*, and the following teeth form the square corners by removing successive chips (as shown by the dotted lines) until the square is finished as at *B*. As will be seen, the first tooth has the widest cut, the chip width *a* greatly decreasing toward the finishing end of the broach. Hence, if this hole were finished with a single broach, it would be advisable to vary the sizes of the teeth so that the depth of cut gradually increases as width *a* decreases.

It is good practice to nick some of the wide teeth as indicated at *n*, in order to break up the chips, as a broad curved chip does not bend or curl easily. In case two or more broaches are required, the first broach of the set may have a uniform variation in the radii *r* of different teeth, but the depth of cut should be less than for the following broaches which remove comparatively narrow chips from the corners of the square. Several end teeth, especially on the last broach of a set, are made to the finish size. This feature, which is common to broaches in general, aids the broach in retaining its size and tends to produce a more accurately finished hole.

Testing Uniformity of Teeth

When testing a broach to determine if all the teeth cut equally, first use a test piece not longer than 2 × pitch of teeth. Pull the broach through and note the amount of chips removed by each tooth; then "stone down" the high teeth and test by drawing through a longer piece, and, finally, through the full length required. If a broach is warped much, or is otherwise inaccurate, some teeth may take such deep cuts that the broach would break if an attempt were made to pull it through a long hole on the first trial.

Clearance Angles for Broach Teeth

The clearance angle a (Fig. 8) for the teeth of broaches is usually very small, and some broaches are made with practically no clearance. Ordinarily there should be a clearance angle varying from 1 to 3 degrees, 2 degrees being a fair average. A common method of providing the necessary clearance is as follows: All the lands of the hardened broach are first ground parallel and then they are "backed off" slightly by means of an oilstone. Just back of the narrow land (which may not be over 1/32 inch wide) there is a clearance of 2 or 3 degrees, machined prior to hardening.

The clearance space required for the chips depends upon the length of the hole and the depth of the cut. When the cut is light, and especially if the material to be broached is tough, thus making it necessary to use as strong a broach as possible, the clearance space should be proportionately small. The fillet at the base of each tooth should have as large a radius r (Fig. 8) as practicable and the grooves between the teeth should be smooth so that the chips will curl easily. A curved clearance space, similar to that indicated by the dotted line c, is superior to the straight slope, although not so easily machined. The front faces of the teeth are sometimes given a rake δ of from 5 to 8 degrees so that the broach will cut more easily and require less pressure to force it through the holes.

Steel for Broaches

Three kinds of steel are used for making broaches: namely, alloy steel, carbon steel and, to some extent, casehardened machine steel for short "push" broaches. Carbon-vanadium tool steel is especially adapted for broaches. This steel differs from the high-speed steels in which vanadium is also used in that it does not contain tungsten or chromium, but is simply a high-grade carbon steel containing a certain percentage of vanadium. The addition of vanadium to carbon steel imparts certain qualities, the most important of which are, first, the higher temperature to which the steel can be heated without coarsening the grain(thus permitting a greater range in temperature for hardening without spoiling the tool), and second, the tough core which makes the broach stronger and more durable than one made of regular high-carbon steel. The makers recommend hardening carbon-vanadium steel at a temperature varying from 1350 to 1425 degrees

F., the temperature depending somewhat upon the size of the tool. The steel is then drawn to suit conditions, the drawing temperature generally being about 460 degrees F. This particular brand of steel will not harden in oil.

Regular carbon steel that is used for broaches should have from 1.00 to 1.10 per cent carbon. To prevent the steel from warping excessively, the broach should be annealed after the teeth have been roughed out. A successful method of hardening to prevent excessive warping is as follows: After machining the broach and before hardening, heat to a dark red and allow the broach to cool while lying on a flat plate, then heat to the hardening temperature and harden in the usual manner. This method, which is applicable to all tool steels, reduces warping to a minimum and is of especial value when hardening slender broaches.

Straightening Hardened Broaches

Broaches that have been warped by hardening can be straightened at the time the temper is drawn. Place the broach on two wooden blocks on the table of a drill press equipped with a lever feed, and insert a wooden block in the end of the drill press spindle. Heat the broach with a Bunsen burner until the hand can barely touch it; then apply pressure to the "high" side. Continue heating (as uniformly as possible) and bending until the broach is straight, but complete the straightening operation before the broach has reached a temperature of about 350 degrees F., so that the drawing temperature will not be exceeded. With this method the heat required for straightening is also used for drawing the temper, the broach being removed and quenched as soon as the tempering temperature is reached. The temperature is judged by brightening some of the teeth throughout the length of the broach and watching the color-changes as the temperature increases.

Proportions of Broaches for Different Operations

The following examples of broaching taken from actual practice indicate, in a general way, the proportions of broaches for various operations:

Operation 1.—Broaching 15/16-inch square holes in alloy steel gears having hubs 3 inches long. Broaches used: The first or No. 1 broach in the set of three has teeth which increase in diameter from the starting end 0.002 inch; the teeth on No. 2 broach increase 0.003 inch, and those on No. 3, 0.004 inch. The leading ends or shanks of the three broaches are 0.005 inch less in diameter than the 1-inch hole drilled prior to the broaching operation. The pitch of the teeth is ½ inch; the width of the lands, ⅛ inch; the last two teeth on broaches Nos. 1 and 2 are made the finished size; six teeth of the finished size are left on broach No. 3. When more than one broach is used, it is common practice to make the last tooth on one broach and the first tooth on the following broach of the same size.

Operation 2.—Broaching a ⅝-inch square hole, 1½ inch long, in carbon steel. Broaches used: Set of three push broaches (for use under a press), 10¼ inches long; pitch of teeth, 5/16 inch; increase in size per tooth, 0.003 inch (0.0015 on each side). A 21/32-inch hole is drilled prior to broaching.

Operation 3.—Broaching a 9/16-inch hexagon hole, ⅞ inch long, in high-grade carbon steel. Broaches used: Set of four push broaches, 6 inches long; pitch of teeth, ¼ inch; increase in size per tooth, 0.010 inch (0.005 on each side) for first six teeth (because of small corner cuts taken by leading teeth), and 0.003 inch for remaining eight teeth. The last six teeth on broach No. 4 are made the same size.

Operation 4.—Finishing babbitted or bronze bearings, 1½ inch diameter, 3 inches long. Broaches used: Pitch of teeth, 7/16 inch; length of toothed section, 4 inches; increase in size per tooth, 0.001 inch; number of uniformly sized finishing teeth, 3; width of lands, 1/32 inch; size of pilot, 1.495 inch; length, 1¾ inch; size of plain cylindrical section following finishing teeth for producing hard and compact surface, 1.505 inch.

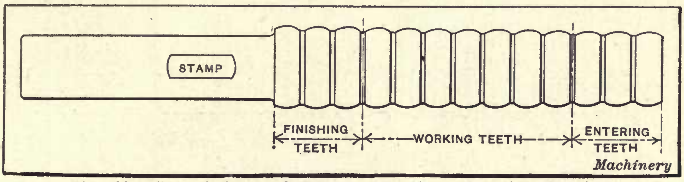


Fig. 10. Smooth Toothed Broach used for machining Bearings

Operation 5.—Broaching the teeth in machine steel internal gears of 3.3 inch pitch diameter; 20 diametral pitch, with teeth ½ inch long. Broaches used: Pitch of teeth (distance between centers of successive rows), ⅜ inch; increase in outside diameter for each annular row of teeth, 0.006 inch; number of rows of uniform diameter, last three. This type of broach is illustrated at *I*, in Fig. 7, and is made as follows: After roughing out the blank, anneal the steel; then mill the teeth the same as if making a long gear; harden and grind the front faces of the teeth to produce sharp edges. The cutting ends of the teeth require little or no clearance.

Smooth-tooth Broaches

Fig. 10 shows a broach of novel design which has the teeth rounded at the top instead of being finished to a cutting edge as in the ordinary type of broach. These teeth are highly polished, and experience has shown that the higher the polish, the better will be the results obtained with the tool. It will be seen that the first few teeth are small enough to enter the hole which is to be broached, the intermediate teeth are of slightly larger diameter, and the last three teeth are of the size to which it is desired to finish the work.

This tool is used for broaching bearings and for operations on other classes of work where the metal is relatively soft, the tool

compressing the metal, and thus giving it a surface hardness. This is of particular value in the case of bearings, on which class of work this broach has found wide application. The amount of metal displaced by the broaching operation is about the same as that removed by reaming, depending largely on the kind of metal and the construction of the broach. Although the tool is primarily intended for operations on babbitt and white bearing metal and brass, it has been used satisfactorily for producing glazed surfaces on cast-iron bearings.

The distance from center-to-center of the teeth depends somewhat on the length of the work which is to be broached. It is desirable to have at least six or eight teeth working at all times. This broach is usually made as shown in the illustration and is pushed through the work instead of being pulled in the ordinary way. An arbor or screw press may be used for this purpose and it is generally advisable to apply lubricant to the broach while in operation.

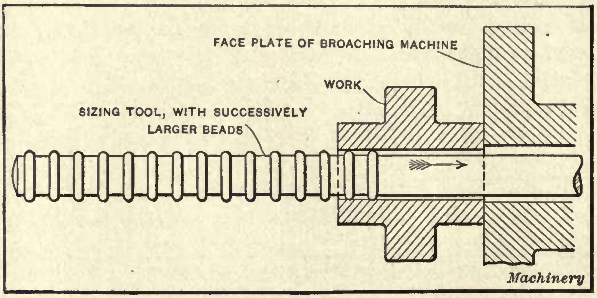


Fig. 11. Method of Sizing Phosphor-bronze in the Broaching Machine by Compression

The noteworthy feature of the operation of a broach of this type, as compared with an ordinary smooth plug, lies in the reduction of friction. It will be evident that the teeth of this broach are fully as efficient as a plug for handling the class of work for which the tool is intended. At the same time, the area of the tool in contact with the work is greatly reduced, with a corresponding reduction of friction and the amount of power required to drive the tool. The provision of teeth also makes it possible to apply lubricant to the work more readily than could be done if an ordinary plug were used.

Sizing Round Holes with Smooth-tooth Broach

Fig. 11 shows how a broaching machine and smooth-tooth broach were used for sizing holes in hard phosphor-bronze bushings. This material, as any mechanic who has had any experience with it knows, is difficult to finish ream. It is tough, elastic and slippery, and the less there is to ream the more difficult becomes the operation. Instead of reaming, the holes are enlarged slightly by pulling a smooth-tooth broach through in a regular broaching machine. It will at once be seen that the operation is that of compressing the metal in the sides

of the hole, until it has been enlarged to the finished size. Each of the rounded rings or beads on the broach is a little larger than its predecessor, thus gradually compressing the metal the desired amount. The finished hole springs back to a diameter a few thousandths inch less than the diameter of the largest ring on the tool, so that the size of the latter has to be determined by experiment. This allowance varies slightly also, as may be imagined, with the thickness of the wall of metal being pressed. In such a part as that shown, for instance, after drawing through the sizing tool in the broaching machine, it will be found that the hole will be somewhat larger in the large diameter of the work than in the hubs. It has been found that this difference in size can be practically avoided by passing the sizing tool through the work three or four times. The operation is a rapid one as compared with reaming.

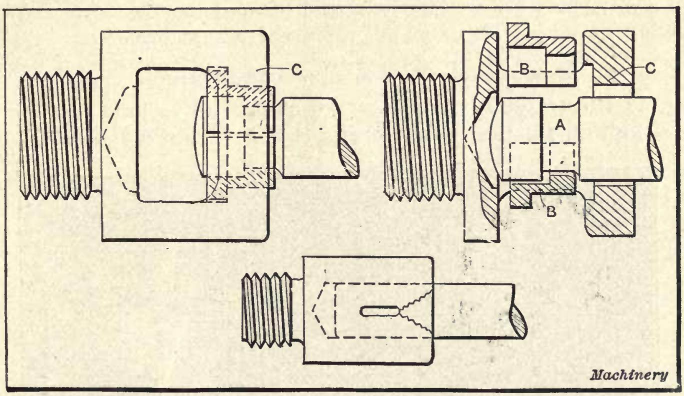


Fig. 12. Design of Pull-bushing for Broaching Machines

Pull-bushing for Broaches

The broaches used on regular horizontal broaching machines are usually secured to the pull-bushing by means of a key passing through the bushing and broach. This connection frequently fails, the pull-bushing giving way as shown by the lower view in Fig. 12, or the end of the broach breaks off. The trouble can be overcome by using a pull-bushing of the type illustrated by the two upper views.

The end of the broach is reduced in diameter as shown at *A*, leaving a shoulder; half-bushings are turned to suit the bore *C* of the pull-bushing and are made to fit freely the end of the broach. The pull-bushing has a slotted hole, wide enough for the insertion of these split bushings.

In use, the broach end is inserted through the hole in the pull-bushing, the half-bushings are placed on the neck and are then drawn back into the hole, as shown by the view to the left. By making the bore large enough when designating a pull-bushing of this form, it is quite a simple matter to arrange for one bushing to

cover a large range of broaches, and in each case retain the greatest possible strength in the broach. Split bushings are made to suit each size of broach. The width of the shoulders in the split bushings should be such that they will break before the strain is great enough to break either the main pull-bushing or the end of the broach.

CHAPTER III

EXAMPLES OF BROACHING PRACTICE

A general idea of the adaptability of modern broaching machines, when equipped with well-made broaches, may be obtained from the following examples, all of which represent actual practice.

Broaching Rack-teeth in a Drop-forging

Fig. 13 illustrates a method of broaching the vacuum cleaner part shown in Fig. 14, the rough forging being illustrated at *X* and the

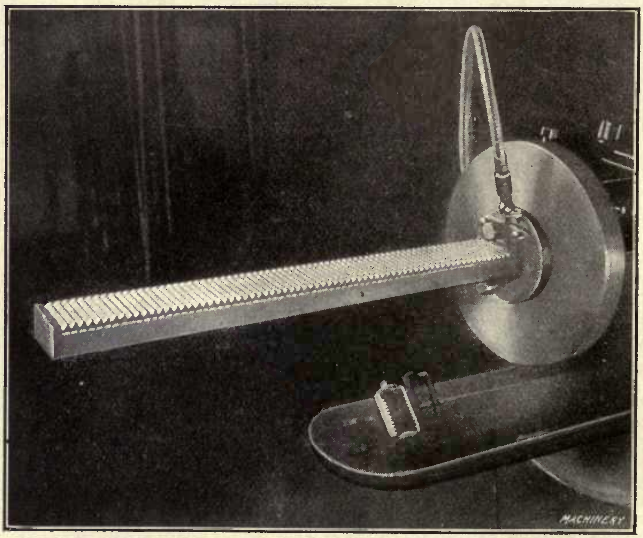


Fig. 13. Broach for Finishing Drop-forging shown in Fig. 14

finished part at *Z*. These pieces are light drop-forgings, and the thinness of the metal at *B* provides very little support to withstand the strain of heavy broaching. In this operation, rack teeth are not only cut (as indicated at *Z*), but also the clearance at *C*, the angular teeth *D* and the end surface *E*, all of these surfaces being finished at one passage of the broach. In finishing these pieces, it is

necessary to have the center line *F-F* equi-distant from the end surfaces *E* and this feature was easily provided for by finishing the pieces on the broaching machine. If the surfaces *E* had been machined by separate operations on any other machine than a broaching machine, there would be a possibility for the introduction of an error at this point.

It will be seen that the pieces are approximately ½ inch thick and that they have a draft *H* on the inside of the forging. The amount of material removed at the dimension *J* was 0.198 inch on each side. The broaching operation would have been easier to handle if this draft had not been necessary. Attention is also called to the fact that the rack teeth were machined with a degree of accuracy which held the dimension *K* within a limit of 0.002 inch, which is exceptionally close

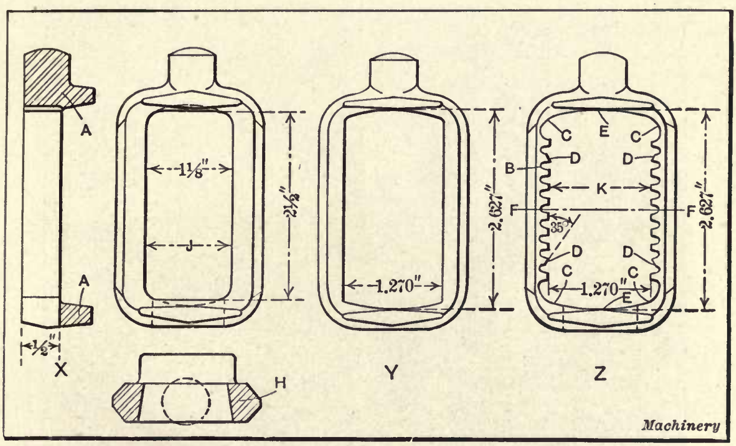


Fig. 14. Method of Broaching a Drop-forging

when the lightness of the work is considered. After the first two thousand pieces had been broached, the first and last pieces of the series were checked in order to determine if any wear had developed in broaching. There was not any error between the dimensions of these two pieces which could be measured. It is stated that in broaching this first series of 2000 pieces, a saving of 80 per cent was made over the time that would have been required to manufacture them by any other method; this saving is net, the cost of the broaches being included in the cost of production.

The broach is made so that the rough forging shown at *X* is first machined to the outline shown at *Y*. After this section was obtained, the clearance at each end, the teeth and the angular cut on the teeth *D* were machined. The gear tooth section was given very little clearance, so that the broach could be sharpened at the front of the teeth; this feature greatly increased the life of the broach. This broach will machine at least 6000 pieces at a rate of production of about 30 pieces per hour.

Broaching Heavy Bench-vise Bodies

The rectangular hole in the back jaw of an ordinary machinists' bench vise is an interesting example of broaching. A common practice has been to cast the back jaws with the rectangular opening cored as closely as possible to the required size and to fit the sliding jaw bar to it by filing. The result, of course, is considerable hand labor and more or less unsatisfactory work in many cases. The application of the broaching machine enables the vise manufacturer to cast the back jaws with smaller openings and to remove metal all around the inside of the hole with the broach. This insures perfect bearing and working surfaces free from hard scale.

Fig. 15 shows an equipment used by a vise manufacturer for broaching the holes in heavy vises. The chief feature of interest,

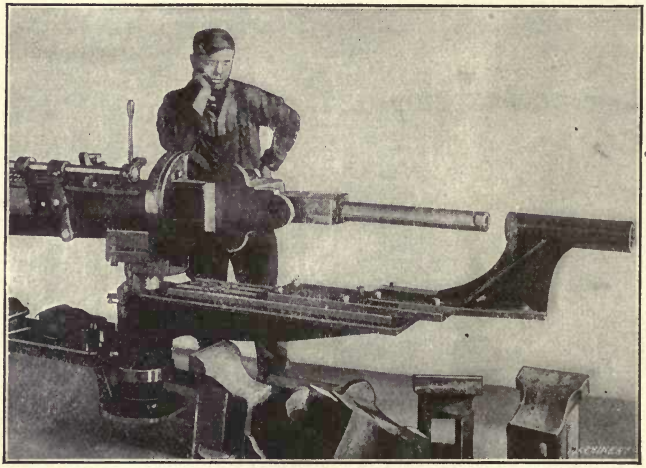


Fig. 15. Broaching Machine Finishing Rectangular Hole in Vise Body

aside from the general operation, is the means provided for supporting the heavy broach. The broach weighs 275 pounds and is, therefore, entirely too heavy to be lifted by hand. The necessity of handling the broach at each operation is neatly avoided. The broach is provided with a round shank at the rear, which telescopes into a supporting bracket. The bracket holds it up in line with the pulling shaft and thus eliminates the necessity of the operator's handling it. The round shank enables the broach to be turned readily to clean off the chips.

The vise jaw weighs about 150 pounds. It is mounted for broaching with the broach as indicated in Fig. 16, and the broach is then slipped up over the pulling shaft which projects out of the machine and is connected with a key. As soon as the machine begins to pull the broach through the vise jaw, the teeth come in contact with the metal all around and by the time the supporting shank of the broach leaves the bracket at the rear, the pressure developed is sufficient to

hold the broach and vise jaw in position. The bracket for supporting the broach is pivoted on the round column beneath the end of the machine bed, and can be swung around beside the bed out of the way when the machine is being used on lighter broaching work. The time required for broaching a jaw varies from four to five minutes.

Broaching Taper Holes

The broaching machine is adapted to the broaching of taper holes when provided with a special fixture as shown by the diagram Fig. 17. The shape of the hole broached in this particular instance is shown in Fig. 18. It is evidently impossible to complete the forming of a square taper in one operation with a solid broach, as this would require a broach made in sections and guided in such a way as to travel in

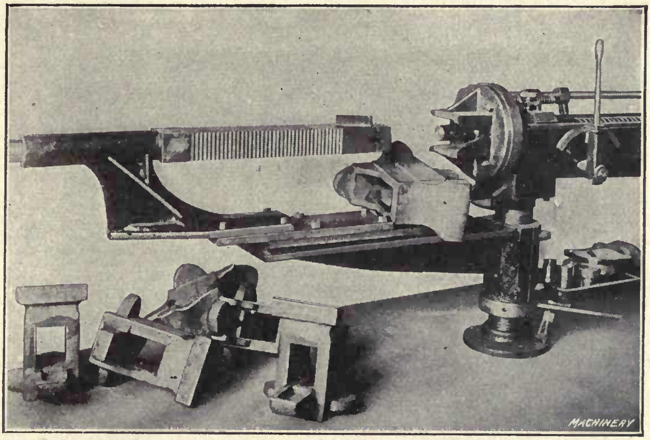


Fig. 16. Showing Heavy Broach supported on Bracket ready for placing Work in Position

paths at the proper angle with each other to give the required taper. In the case of small work like that here shown, the plan is followed of cutting one corner of the taper at a time, and then indexing the work to four successive positions until each corner has been cut, which thus finishes the entire hole.

As indicated by the dotted lines in Fig. 18, the hole to be broached is first finished with a taper reamer slightly larger at the large and small diameters than the width across the flat sides of the finished taper hole at the large and small ends. This gives a little clearance space for the broach on each of the operations. This round tapered hole also serves as a seat for the taper bushing on which the work is supported during the cutting operation, and as the broaching does not entirely clean out this hole, the bearing remains to the completion of the final operation. The work bushing is turned on its outside to the taper of the hole in the blank, and is mounted at the head of the machine on a base which is inclined to the angle of the corner of the internal taper to be cut. In a groove formed on

the under side of this tapered work bushing, slides the broach or cutter bar (see Fig. 17), having teeth formed in it after the usual fashion of such tools, smaller at the inner end and gradually increasing in height to the outer end until they conform to the full depth of the cut to be made. The work has clamped to it a dog with a slotted tail, adapted to engage any one of four pins disposed equidistantly about the edge of a disk which forms the base of the taper

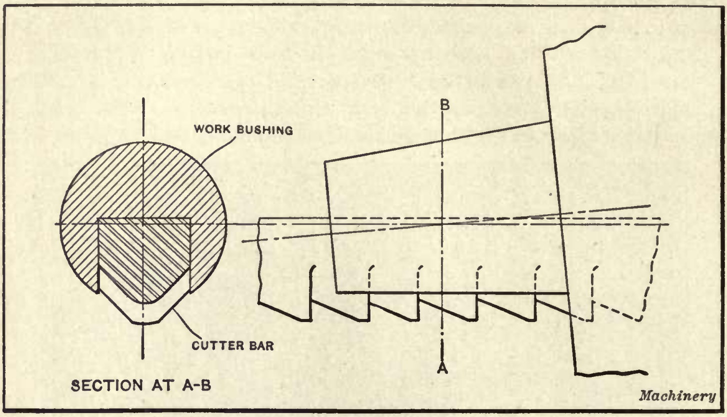


Fig. 17. Device used for Broaching Taper Holes

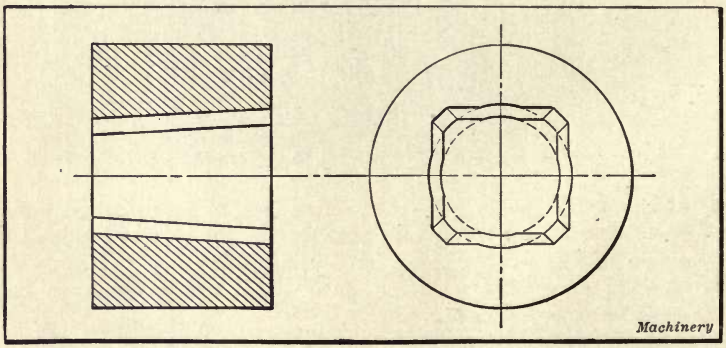


Fig. 18. Taper Hole Broached by Means of the Device shown in Fig. 17

work bushing. By means of these pins the casting is indexed for broaching the four corners.

In operation, the broach having been run out to the extreme of its travel, the work is inserted over the broach and pushed on to the taper work-holding bushing, and is located as to angular position by engaging the dog with one of the four pins. The machine is then started up and the broach is drawn back through the work, cutting out one of the corners. Then the blade is again run out, the work is drawn off by the taper bushing far enough to permit rotating it until the dog engages a second pin, when the operation is repeated, cutting

out a second corner. The other two corners are successively finished in the same way, thus completing the machining of the hole to the form shown in Fig. 18.

It may be noted that while the hole shown has flattened corners, these are not required, as the broach can be made with a sharp corner if necessary. In all cases, however, it is necessary to leave a portion of the taper hole in the flat of the square so as to center the work with the bushing. Less of the circle, however, can be left than is shown in the engraving. For instance, at the large end the round taper hole need be only about 0.010 inch deeper than the square to be cut.

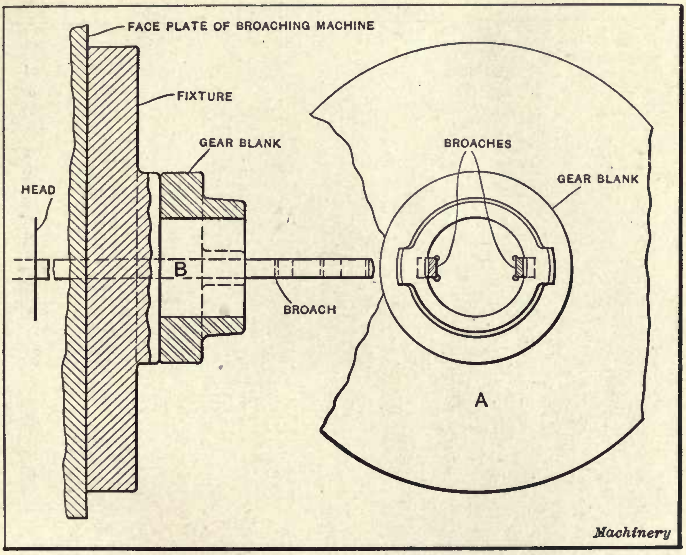


Fig. 19. Fixture used for holding Gear Blanks while broaching Two Keyways in One Stroke of Machine

Broaching Keyways in Gear Blanks

An interesting fixture for holding a gear blank while broaching two keyways in it is shown in Fig. 19. This gear blank is made from a vanadium steel drop-forging, and the broaching length is 1⅜ inch, two keyways which are 5/16 by 5/32 inch being cut in one pass of the broaches. In cutting these keyways it is not necessary to remove the broaches, which are held in the head, as the operator simply allows the head of the machine to advance toward the fixture, then grips the two broaches, closing them together, and slips the work over.

The broaches *B* have no teeth for a distance of about 2½ inches from the face of the fixture, so that when these are held together it is a simple matter to slip the work over them and locate it on the fixture *A*. It is evident that when the head of the machine travels

away from the fixture, the broaches are drawn in, and as they are made thicker toward the outer ends, they cut the keyways to the correct depth. The illustration shows how these broaches are guided when in operation on the work. Holding the broaches in the manner shown, enables a large production to be obtained, the time generally taken in removing and replacing the broach being saved. On an average, 800 gear blanks are broached in ten hours, which means that 1600 keyways are cut in this time. The possibilities of broaching when suitable fixtures are provided are almost unlimited, and the job described in the preceding illustrates the adaptability of the broaching method to the cutting of keyways in gears.

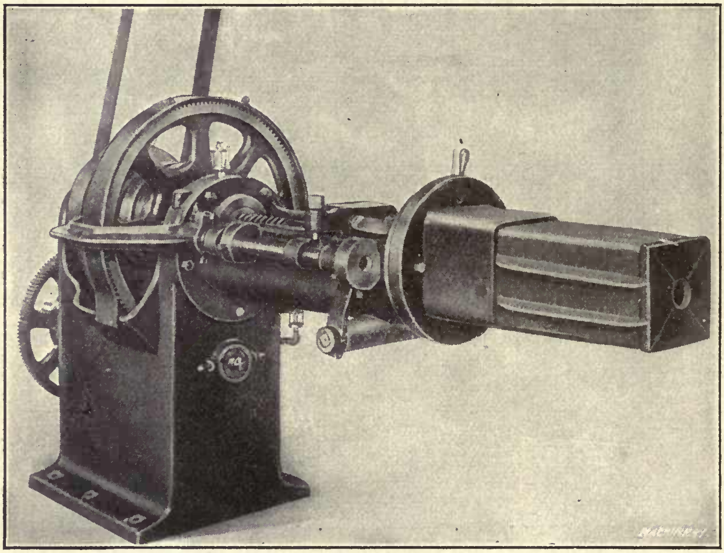


Fig. 20. The Broaching Machine with the Work in Place

Broaching a Large Steel Casting

Figs. 20 and 21 show a broaching machine provided with special cutting tools, and engaged on an exceptionally heavy broaching operation. The size of the hole to be broached is approximately 8 inches square, though the hole is not really square, being of the special shape shown in Fig. 22. Not only is the work remarkable on account of its size, but also because the surfaces had to be broached on a taper, the outer end of the hole being ½ inch further across than at the bottom, while the work is rendered still more difficult from the fact that the opening is closed at the small end. The method of broaching this casting is to begin at the bottom and work outward. A recess 3 inches long and about ¼ inch deep is furnished at the bottom to provide a clearance space for starting the broach. The stock to be removed on each of the finished surfaces of the work is

about 1/16 inch thick; the total area to be broached is 14 inches long, with a developed width of 24 inches. In the center of each face of the hole, it will be noticed that there is a half-round recess; no broaching is done in this part.

The machine used is an unusually large size which operates on the same principle as the machines previously referred to. The mechanism consists primarily of a threaded draw bar or ram, operated by a revolving nut, driven by suitable gearing and reversing mechanism, this mechanism being operated by dogs and adjustable stops to give the required length of operating and return strokes. Practically the only special feature of the equipment is the special broaching head

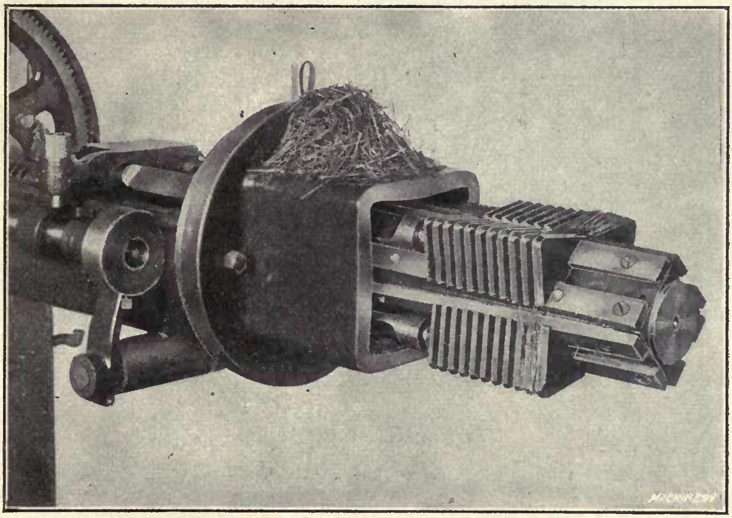


Fig. 21. The Taper Broach used for Broaching the Steel Casting shown in Fig. 22

and broaches used. These are of such unusual size and ingenious construction as to be of decided interest.

The construction of the broaching head is plainly shown in Fig. 21. It consists essentially of a central square mandrel, tapered to the taper of the hole to be finished in the work, and provided with ways in which slide four separate broaches—one for each corner of the work. These broaches are connected with the head of the ram of the machine by bars, which are milled down thin enough to have sufficient flexibility to permit the broaches to spread apart as they approach the inner end of the stroke, and come together again as they return to the starting position on the outer end of the mandrel. Each of the broaches is made of a solid piece of tool steel, with a series of 13 teeth of suitable shape milled in it.

In operation, the ram is first extended to the outer limit of its stroke, with the broaches at the outer and smaller end of the square

central mandrel. The work is then placed over the mandrel as shown in Fig. 20, in which position the broaches nearly touch the closed bottom of the hole. The outer teeth in this position are in the recess. The machine is then started up, and the revolving nut, and threaded ram pull the broaches up on the tapered guides of the square mandrel, by means of the flexible pulling rods.. As the broaches are thus drawn inward on a gradually expanding form, they cut the required shape in the interior of the steel casting. The broaches first are tapered, so that the outer end is 1/32 inch larger than the end to which the pulling rods are connected, this being the amount which is to be removed from the work in each operation.

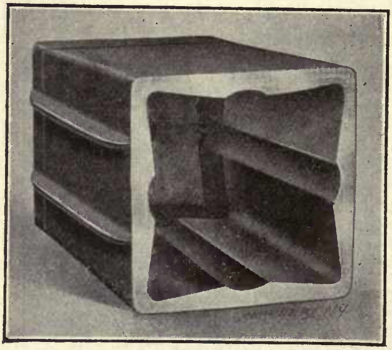


Fig. 22. Large Steel Casting Broached as Illustrated in Figs. 20 and 21

As is shown in the engraving, a special abutment or base is provided for taking the thrust of the work as it resists the action of the cutters. Piled up on this special base, in Fig. 21, will be seen the chips produced at one stroke of the machine. It will be noted from their character that a cutting action is effected by the broaching blades. The approximate pulling strain on the four rods operating the broaches is estimated to be from 75 to 100 tons.

Broaching Round Holes

The broaching of round holes has been adopted within the last few years by many manufacturers on certain classes of work in preference to reaming. This change is due to two reasons: The cost of the operation is less and the finish on the particular work referred to later is superior to that of reaming.

It is an acknowledged fact that the boring and reaming of seamless steel tubing, especially when the walls are light, is not a very satisfactory operation; in fact, the pieces are usually distorted, due to the method of holding them. One of the principal objections to reaming, and one reason why it is so hard to obtain a well reamed hole in steel tubing, is that the reamer tears or "bites in" at some point on the surface. This is due to the fact that the fibers of the steel are drawn lengthwise or at right angles to the cutting edges of the reamer, which is one of the reasons why it is so hard to obtain a good clean finish in steel tubing by reaming.

On the other hand, when broaching the hole in a tube, a very nice finish can be obtained because the fibers lie or are drawn in the same direction as the broach is operated. The ordinary seamless steel tubing is about 0.008 to 0.030 inch under standard size, which is about

the right amount to broach out. For broaching this material, with diameters up to 2 inches, the high speed of the broaching machine can be used, the cutting tool traveling at about six feet per minute. There is no clamping of the work for this operation and the shell is not distorted as much as it would be by boring or reaming. Six or seven pieces can be broached while one is being reamed.

Broaching Round Holes in Steel Gears

The method of machining the holes in sliding and differential gears, adopted by one of the largest automobile gear manufacturers in the country, is as follows: The work is placed on a drill press, in a suitable fixture, and the holes, which vary from 1 1/16 to 1 1/2 inch in diameter, are drilled in one operation with a drill 1/32 inch smaller than the finished size of the hole. On the spindle of the drill press a facing head is arranged so that after the hole is drilled, the spindle is fed down and the gear faced off by this facing head; this forms a flat surface which is square with the hole and is used for locating the work while the holes are being finished by broaching. The old method was to drill these gears, then follow with a light boring chip, and then a reamer. The reduction in cost obtained with the new method is 1½ cent per hole, which is quite an item when we consider that the original cost of machining the holes was very low. The results obtained by broaching are that a well finished hole is obtained in addition to greater production; moreover, the life of a broach is eight to twelve times that of a reamer.

Broaching Round Holes in Bronze Bearings

Another operation of broaching round holes is that of finishing holes in bronze machine bearings, up to about 2½ inches in diameter. Take, for instance, the broaching of a 2-inch round hole in bronze castings 4½ inches long. It is the practice in one shop to allow ⅛ inch of stock to be removed or 1/16 inch on each side, the hole being cored 1/8 inch smaller than the finished diameter. When these bearings were being bored and reamed to size, ¼ inch was allowed and the average time was 10 minutes per piece. They are now broached at the rate of one in 1¼ minute and the pieces are not clamped and do not lose their shape. The finish of the broached holes is better than was obtained by reaming. The trouble when reaming hard bronze is to overcome the chattering and waving of the reamer in the hole; this has been done by broaching.

Broaches for Round Holes

The results when broaching round holes depend on the tool itself. The broaches are ground all over after hardening and are backed off at the proper angle to give them a nice cutting edge. The teeth are nicked to break the chips on the heavy cutting part of the broach, but the last six or eight teeth that do the sizing are not nicked. Following the last six or eight sizing teeth is a short pilot which supports and guides the broach. One very important thing in

broaching round holes is the proper spacing of the broach teeth. At no time must there be less than three teeth in the work, in order to properly support the broach; if the teeth were so coarse that only one tooth was cutting while another was entering, it would give the broach a slight movement, causing waves in the work. The broach must always be made up with differential or uneven spacing of the teeth. If the teeth are all evenly spaced, as a rule unsatisfactory results will be obtained.

When making broaches a number of things must be taken into consideration, *viz.*, material to be cut, length of work, amount of stock to be removed on the outside, and the shape of the work, so that the proper support can be provided. The length of the broach depends entirely on the metal to be removed. Of course in cases where the

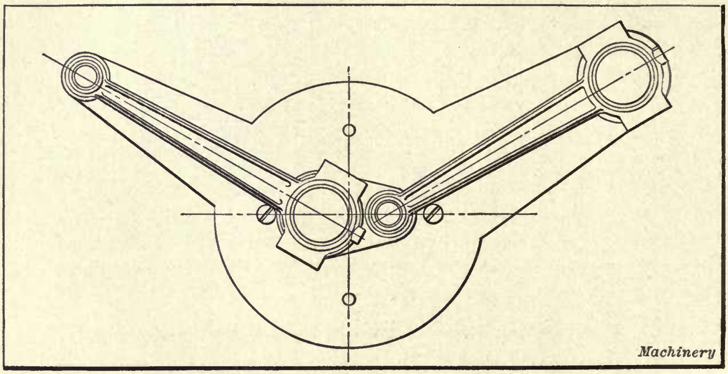


Fig. 23. Engine Connecting-rods, and Fixture Used when Broaching

broaching operation is for sizing, a short broach is used, usually having about 10 inches of cutting edge. If the broach is to remove ⅛ inch of stock, the length may vary from 28 to 40 inches, depending on the length of the work.

Broaching Round Holes in Chrome-nickel Steel

It has been demonstrated that the broaching of hard chrome-nickel steel, such as is used in automobile work, is a much cheaper process than reaming. A typical job is shown in Fig. 23, which illustrates two connecting-rods and their broaching fixture. The small end of one rod and the large end of the other are broached simultaneously and one complete rod is finished for every stroke of the machine. The fixture is not absolutely necessary but adds considerably to the production. These connecting-rods are first drilled to the size of the broach shank or to a diameter of from 0.015 to 0.018 inch under the required size. They are then finished by broaching, thus eliminating both machine and hand reaming. After the rods have been broached, the large end is split and the lining bushing for the large end is inserted. The bushing for the small end is pressed into the rod. These bearings or bushings are then broached.

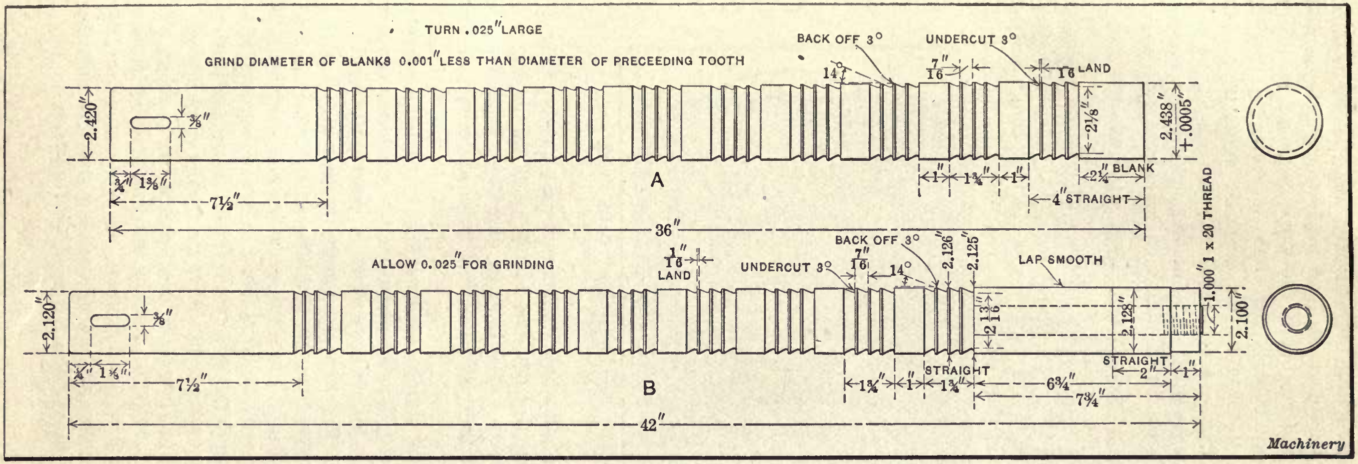


Fig. 24. Broaches used for Connecting-rods shown in Fig. 23

The broach illustrated at *A* in Fig. 24 is used for broaching the hole in the large end of the rod, whereas the smaller broach *B* is for finishing the bushing. The plain round sections seen on these broaches are for the purpose of keeping the broach from "running" or "crawling," as it is essential that the center-to-center distance of these rods be kept fairly accurate. By introducing plain blanks or sections between the teeth, as shown, the broach is kept properly aligned with the hole because there is always some portion of the blank section in the work while some of the teeth are cutting. In other words, the blank sections serve as guides and prevent lateral movement.

When using a broach, it is passed through the work and is fastened to the draw-head of the machine by a cotter-key which passes through the slotted end in the usual way. Only such clamping as is necessary to support the work is required as the blank sections on the broach will hold the part in alignment. When using these broaches in cast iron, a soap cutting compound is used, as this gives the broached surface a highly polished finish. For chrome-

nickel steel, a good grade of cutting oil will give satisfactory results. On some work, no drilling whatever is done prior to broaching, and very often only one broach is used, but if the work is longer than say two inches, a roughing broach usually precedes the finishing broach. Of course, broaching from the rough can only be done when the broaching operation comes first, as otherwise the broach would follow the rough hole and, consequently, the finished hole would be out of true with any other surfaces which might be machined afterward.

Broaching Round Holes in Vanadium Steel

The following example represents the practice of a large automobile manufacturer in the broaching of round holes in vanadium steel forgings: The forging, which is 5½ inches long, is first rough-drilled in a high powered vertical drilling machine, from 0.005 to 0.010 inch

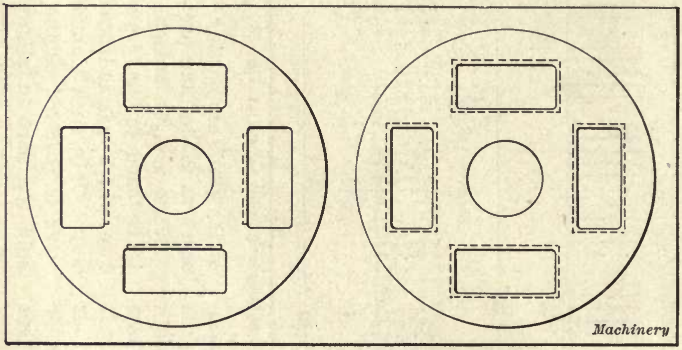


Fig. 25. Plan View showing Four Rectangular Holes which are Finished by Broaching in Two Operations

being left on the diameter of the hole to be removed by the broach. The forgings are taken from the drilling machine to the broaching machine and the hole, which is 1 3/16 inch in diameter, is completed in one pass of the broach, a production of 750 being obtained in ten hours.

The fixture used is of very simple construction, consisting simply of a cast-iron ring fastened to the faceplate of the machine, against which the forging is held by the broach as it is drawn through. A small straight portion about 1¼ inch in length is provided on the end of the broach, which passes through the hole and gives it a burnished appearance. The hole is superior as a bearing surface, to that produced by a reamer. This is because when the reamer is working in alloy steel, especially that containing a percentage of nickel, it usually tears rings around the hole, producing a rough surface. The broach, on the other hand, if it scratches or tears at all, makes these in a line parallel with the axis of the work, which is less detrimental to a bearing surface than annular grooves. Another advantage of broaching round holes instead of reaming them is that the broach retains its size much longer than a reamer.

A Special Broaching Operation

The progress which has been made in the broaching machine and its use is illustrated by a broaching operation which is being performed at the factory where universal joints for automobiles are manufactured. Fig. 25 shows two plan views of the piece which is to be broached, showing the work done at each of the two operations. Fig. 26 illustrates the special broaching fixture and broaches used for doing the work, and part *E* is the rough steel forging upon which the broaching is done. This is one of the parts of a universal joint. It is one inch thick, having four roughly formed rectangular holes, which must be broached on all four sides, finishing each hole to an accurate size; moreover the broaching must be so done that the finished holes will all be equi-distantly spaced from the central hole.

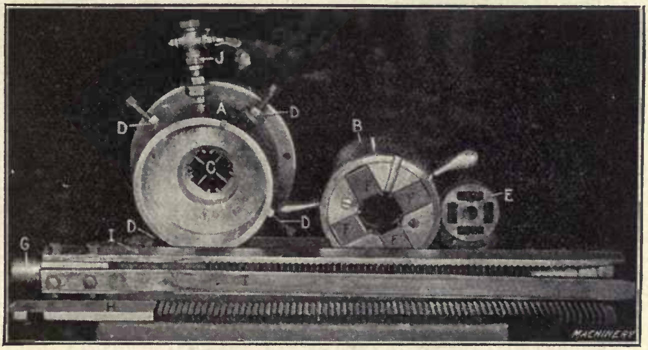


Fig. 26. The Broaches and Broaching Fixture used for the Operation Illustrated in Fig. 25

This central hole is finished by drilling and reaming and the outside edge of the piece is turned, so that the piece may be held by the edge.

Referring to Fig. 26, it will be seen that the broaching fixture consists of a very heavy faceplate casting *A* that fits on the head of the broaching machine, and this casting is bored out to receive the other half of the fixture *B*, which acts as a guide-sleeve.

The faceplate *A* is fitted with four hardened steel guides *C* which are adjustable radially by means of set-screws *D*. It will be noticed that these guide-blocks are slotted to receive and guide the broaches while they are cutting. The piece to be broached indicated at *E*, is a snug fit for the smaller bored hole in casting *A*, allowing it to seat close to the guide-blocks *C*. After being placed in this recess, guide-sleeve *B* which is a sliding fit for the large bored section in faceplate *A*, is inserted. This part of the fixture is also provided with four hardened steel guide blocks *F* which may be adjusted radially after the manner of chuck jaws. Guide-sleeve *B*, while free to slide in faceplate *A*, is prevented from turning and throwing the two sets of guide-blocks out of line, by means of suitable tongues.

There are two operations required to complete the broaching on this piece. At *G* is shown the broach holder with the four broaches *I*, used for the first operation. One of the features of this job is that four cuts are made at each draw of the machine. The first operation is performed after adjusting the position of jaws *C* and *F*, so that when the four broaches *I*, held on broaching head *G*, start to cut, they will clean out a place on the inside edge of each of the four holes, leaving the forging with four cuts as indicated by the dotted lines in the left-hand view in Fig. 25. It will be seen that by adjusting the guide-blocks *C* and *F*, against which the blank sides of the first operation broaches bear, the broaching may be controlled as regards its distance from the central hole in the forging.

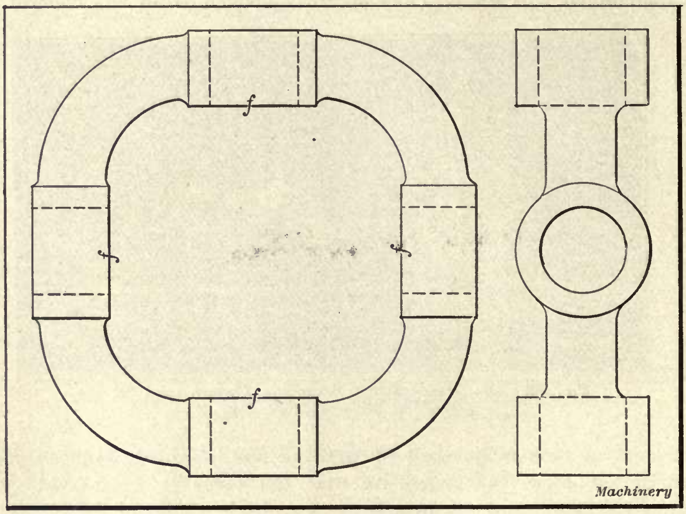


Fig 27. Ring-coupling to be broached

This completes the work done at the first operation. The second operation is performed with the aid of four broaches, one of which may be seen at *H*, which are held upon the same broaching head *G*. These broaches are provided with one flat side which bears against the surface already broached. Teeth are provided on the opposite side and the two edges, so that the other three sides of each of the four holes are broached out true with the four surfaces already broached, thus cleaning the holes out on all four sides and insuring that the finished holes will be true with the central hole. Lubrication is provided through pipe *J* which enters the faceplate casting opposite the cutting point.

In broaching these parts, the entire lot is run through the first operation and then the broaches are changed and the second operation performed. The broaches are not removed from the machine after each pass, as is necessary in most broaching, for as they do not

cut to the full width of the hole, and as they are spring-tempered and beveled at the ends, they may be pressed together and the forging slipped over them to the starting point. The broaches are made of slightly different lengths so that they do not all begin cutting at once.

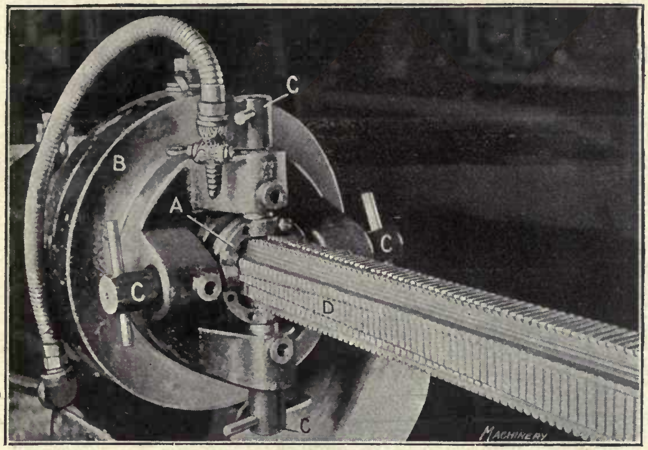


Fig. 28. Broaching the Ring-coupling

These pieces are broached at the rate of thirty-six operations, or eighteen completed pieces per hour.

Broaching Flat Surfaces

The operation of broaching is too often viewed in the light of a process used principally for cutting keyways or square holes, but with

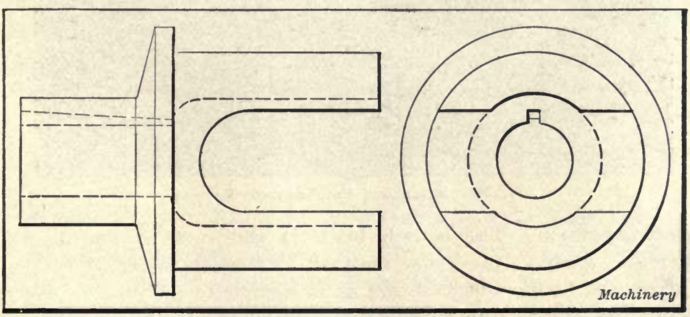


Fig. 29. Universal Joint Yoke in which Tapered Keyway is to be Broached

proper equipment the broaching machine is really a machine tool capable of handling a great many otherwise impracticable jobs. Incident to the manufacture of automobile parts there are many interesting broaching operations.

One of these jobs consists of broaching the inside of a ring-coupling which is a part of a universal joint. The ring-coupling, which is shown in Fig. 27, has been previously drilled and broached through

the four round holes and it is essential that the inside faces (marked *f*) be finished true with the holes. In order to accomplish this successfully, the work is held upon a special fixture which is mounted upon the faceplate of a broaching machine. Fig. 28 illustrates the method of holding and broaching the work. The work, shown at *A*, is supported on the fixture *B* by means of four pins *C* which engage the holes in the coupling. These pins are merely a sliding fit through the bosses of the fixture, and the cross handles are added to assist in

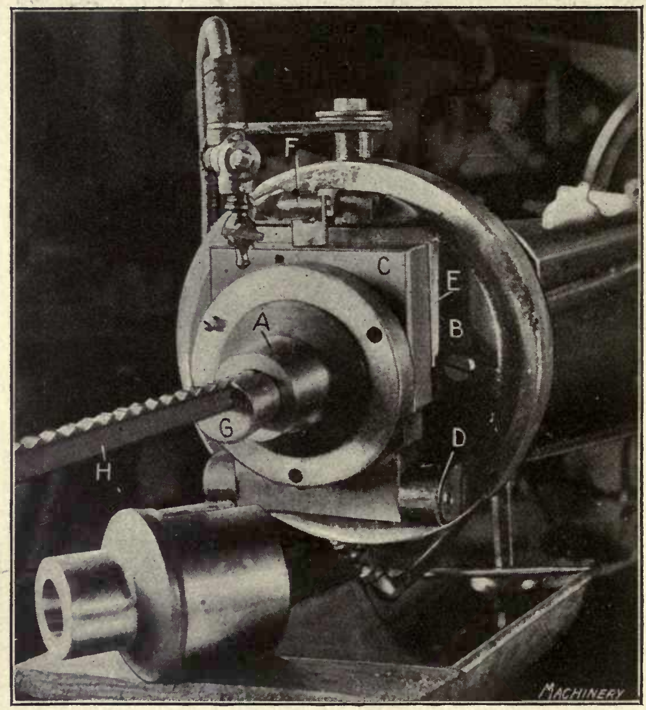


Fig. 30. Broaching the Tapered Keyway

withdrawing them. The broach itself is shown at *D* and is pulled through the work in the usual manner. In order to facilitate centering the broach in the work as well as to distribute the cutting over the length of the broach, the cutting surfaces of the teeth are made very narrow at the beginning of the tool, gradually increasing in width until at the end of the work they are full width, finishing the entire surface. These pieces are broached at the rate of twenty-five per hour and the surfaces are finished true with the holes.

Broaching a Tapered Keyway

Cutting the tapered keyway through the yoke shown in Fig. 29 is a broaching operation that has some interesting features. The key-

way must be cut through the bore of the work at an angle of 10 degrees. The cut is 5/16 inch deep at the beginning and only 5/32 inch deep at the end of the cut. The method of doing the work is illustrated in Fig. 30, in which the yoke is shown in the foreground and also on the machine at *A*. It is supported on the special fixture *B* which consists of a faceplate provided with a leaf *C* that is hinged at *D*. This leaf is held in an upright position by a clamp *F* and the work *A* fits closely in the bushing in the leaf *C*. As the broaching must be done at an angle to the machined hole, the leaf of the fixture is not held at right angles to the broach, but is backed up by a tapered wedge *E* so that the work is thrown off at an angle to the broach.

When broaching, the work is placed in the leaf of the fixture and the tapered plug *G* is entered into the hole around the broach *H*. This

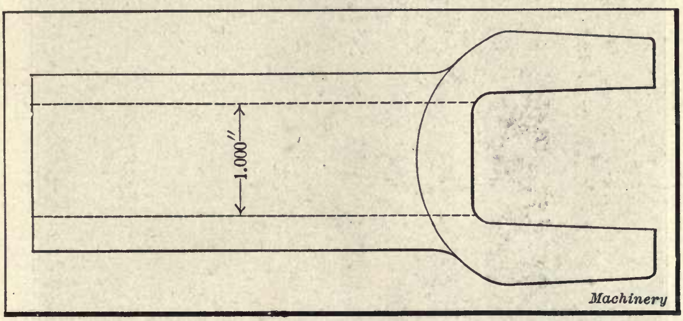


Fig. 31. Slip-hub in which the Round Hole is finished by broaching

plug is cut out to receive the broach, and serves as a guide, preventing the broach from springing away from the work. The broaching is then carried on in the usual manner. When broaching must be done at a different angle it only requires the substitution of a wedge of the required angle at *E*. Thus the fixture can be used on more than one job. This broaching operation is performed at the rapid rate of thirty-three pieces per hour.

Broaching a Round Hole in Alignment with Other Surfaces

The universal slip-hub shown in Fig. 31 is first rough-drilled throughout its length. It is necessary, however, that this hole be finished true to size and exactly in line with the projections at the end. This is accomplished by broaching, as shown in Fig. 32; in this illustration the piece may be seen lying beneath the fixture. The fixture which is shown at *A* has a leaf *B* provided with an adjustable bushing *C*. The leaf is dropped and the work placed within the fixture so that the projecting lugs are centered. Then the leaf is replaced and secured with pin *G*, and the bushing is screwed up against the work so that the countersunk inner end will engage the piece from the outside edge and hold it in a central position ready for broaching.

The broach is then inserted and one pass finishes the piece, leaving it exactly to size and finished as smooth as if done with a reamer. Twenty-five broached pieces per hour is the rate of production.

Broaching a Dovetail Keyseat in a Taper Hole

It was desired to broach a dovetail keyseat in the crank-shaft hole of a large quantity of bicycle cranks. The cranks were of nickel steel

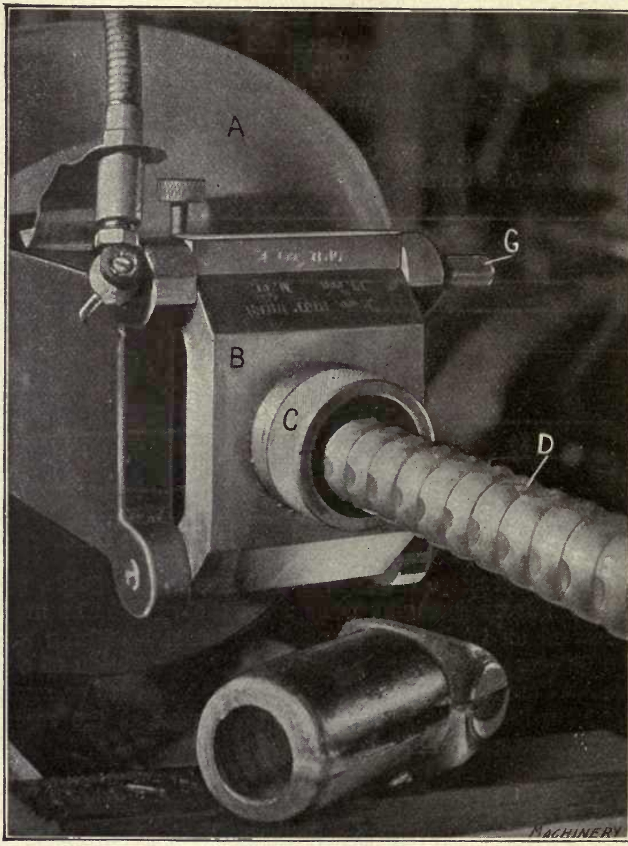


Fig. 32. The Broaching Fixture for the Slip-hub

and had a 10-degree taper hole in the hub, with a minimum diameter of 17/32 inch. It was necessary to broach the hub to receive a flat key, 3/8 inch wide by 1/16 inch thick, dovetailed to a 10-degree included angle. When the keys were driven into place in the cranks, the latter were required to be interchangeable on the crank-shafts, which were slabbed off on one side of the taper end to correspond with the key in the crank, and fitted with an ordinary check-nut to retain the crank.

To fit a key in this manner and insure interchangeability and a simultaneous fit on both key and crank, requires a nice degree of accuracy;

considering this, and the toughness of the steel, as well as the necessarily limited diameter of the broach, it was expected that the operation would prove expensive. Subsequent experience with the use of the device here illustrated, however, proved otherwise, as thousands of the parts were broached most successfully at a remarkably small cost.

Fig. 33 shows the piece to be broached. Fig. 35 shows a machine steel plate, planed on the bottom and sides to fit the die-bed of an

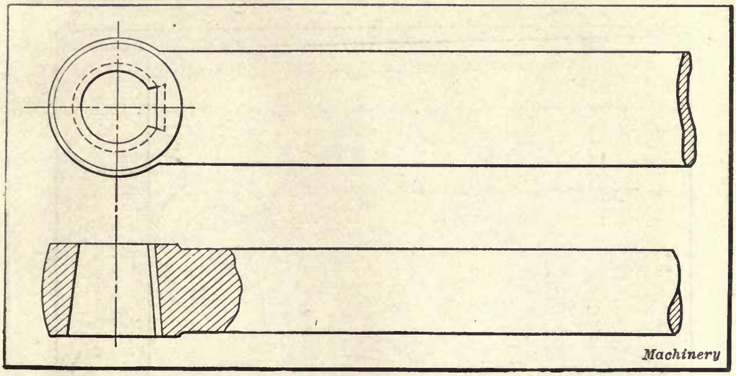


Fig. 33. Bicycle Crank, in Hub of which Dovetail Keyseat is Broached

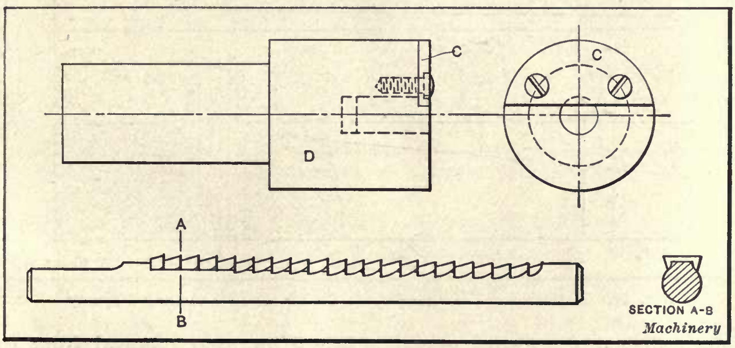


Fig. 34. The Broach and Holder used for Broaching Bicycle Crank

ordinary 8-inch stroke drawing press, and planed on the top to an angle of 5 degrees. After the planing operation a hole was bored at right angles with the top surface, to receive a tempered guide bushing *A*, which was pressed into place. The guide hole for the broach was then put through at right angles with the bottom of the plate. Thus it will be seen that when the crank is placed in position over the guide bushing and brought into contact with the stop pin *B*, the surface to be broached will be parallel with the line of travel of the broach.

Fig. 34 shows one of a series of three broaches which are required to complete the cut. These are made to slide freely through the guide bushing *A* (Fig 35), and are held in the proper position in the holder

D by means of a locating piece *C*. As the press reaches the limit of the downward stroke, the broach, which has ceased cutting, simply drops through the bushing into the hand of the operator, who then inserts broach No. 2 into the holder as the press reaches the upward limit, thus making it unnecessary to stop the machine to insert the tools. Great care should be experienced to keep the teeth of broaches of this kind free from chips, which can easily be accomplished by the operator pass-

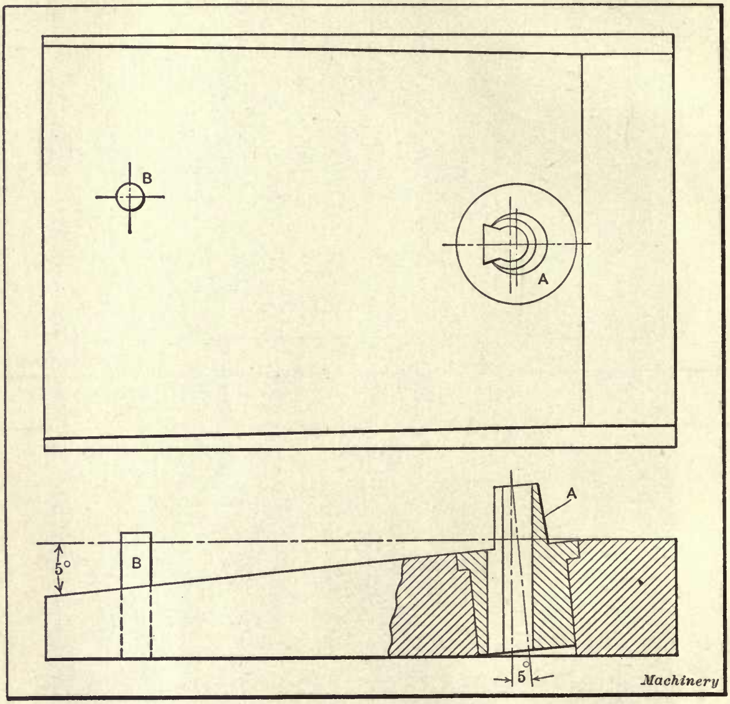


Fig. 35. Fixture for Holding Bicycle Crank while Broaching Keyway

ing his fingers downward over the face after each removal from the guide bushing, and before depositing in the pan of oil.

In tempering broaches of the shape used in this operation, the best results can be obtained by slowly heating the piece, face downward, in a charcoal fire. When heated face upward, the piece will invariably bend, making the face concave, and as they require to be reasonably hard, it is a difficult matter to straighten them.

Time Required for Broaching Operations

Some typical broaching operations are illustrated in Fig. 36. The dimensions of these parts and the number broached per hour are given in the following:

Sample A: ¾-inch square hole; sharp corners; 1⅜ inch long; 40 per hour.

Sample B: 15/16-inch square hole; sharp corners; 1 1/2 inch long; 40 per hour.

Sample C: 1⅜-inch square hole; sharp corners; 4 inches long; 15 per hour.

Sample D: 1 3/32-inch square hole; round corners; 2 inches long; 40 per hour.

Sample E: 1⅜-inch square hole; round corners; distance across corners, 1¾ inch; 1½ inch long; 40 per hour.

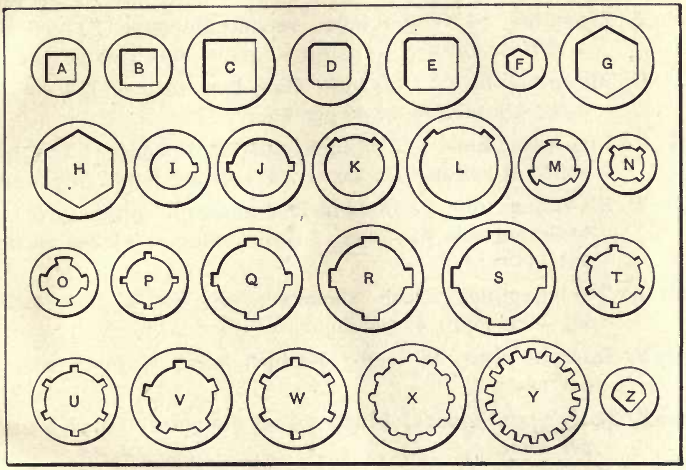


Fig. 36. Typical Examples of Broaching Operations

Sample F: ⅝-inch hexagon hole; 1⅜ inch long; 40 per hour.

Sample G: 1⅝-inch hexagon hole; 2 inches long; 35 per hour.

Sample H: 1¾-inch hexagon hole; 1½ inch long; 35 per hour.

Sample I: 1-inch hole; ¼ by ⅛ inch keyway; ½ inch long; 210 per hour.

Sample J: Two-spline hole; 1½-inch diameter; 5/16 by 5/32 inch splines; 1½ inch long; 80 per hour.

Sample K: Two ½ by ¼ inch keyways in 1½-inch holes; 3 inches long; 40 per hour.

Sample L: 2-inch hole; 3/4 by 5/16 inch keyways; 3 inches long; 30 per hour.

Sample M: Three-spline dovetail hole; 1⅛-inch diameter; outside diameter, 1⅜ inch; ½ inch long; 100 per hour.

Sample N: Four-spline 15/16-inch hole; splines ¼ by ⅛ inch wide; 1 inch long; 100 per hour.

Sample O: Four-spline dovetail hole; 29/32 inch; 2 inches long; 40 per hour.

Sample P: Four-spline hole; 1¼-inch diameter; 1⅝-inch outside diameter; width of spline, 5/16 inch; 3 inches long; 40 per hour.

Sample Q: Four-spline hole; 1¾-inch diameter; outside diameter, 2⅜ inches; splines 9/16 inch wide; 4 inches long; 20 per hour.

Sample R: Four-spline hole, 1 7/8 inch; keyways 3/4 by 3/16 inch; 3 inches long; 20 per hour.

Sample S: Four-spline hole; 2⅛-inch diameter; outside diameter, 2½ inches; splines ⅞ inch wide; 2 inches long; 20 per hour.

Sample T: Six-spline, 1 7/16-inch hole; outside diameter, 1 11/16 inch; width of spline, ⅜ inch; 4 inches long; 20 per hour.

Sample U: Six-spline hole; 1 1/2-inch diameter; splines 3/8 by 3/16 inch; 1½ inch long; 40 per hour.

Sample V: Five-spline hole, 1 47/64 inch; outside diameter, 2 3/16 inch; width of spline, 7/16 inch; 3 3/4 inches long; 20 per hour.

Sample W: Six-spline hole; 1 13/16-inch diameter; splines 3/8 inch wide; outside diameter, 2 1/16 inches; 4 inches long; 20 per hour.

Sample X: Twelve-spline; 2-inch diameter; grooves ⅛ inch radius; 1½ inch long; 60 per hour.

Sample Y: Internal gear; 18 teeth; 2⅛-inch hole; ½ inch face; 120 per hour.

Sample Z: ¾-inch semi-square; 1-inch corner diameter; 1 inch long; 80 per hour.